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BACKGROUND SOUND PRESSURE FLUCTUATIONS (5 DB) FROM OVERHEAD VENTILATION SYSTEMS INCREASE SUBJECTIVE FATIGUE OF UNIVERSITY STUDENTS DURING THREE-HOUR LECTURES[1]

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Summary.—During each of four successive sessions (once per week), 21 university students attended 3-hr. lectures. During alternative weeks the fans of the room's ventilation system were either on or off. When operating, they generated an average sound pressure that varied continuously between 60 and 65 dB. The dominant frequency of this 5-dB amplitude modulation of sound pressure was within the electroencephalographic range (5 Hz to 25 Hz). At the end of each hour of the lecture for each session each student estimated on 7-point summated rating scales fatigue (none to maximum) and concentration (poor to excellent). As a group, the students reported more fatigue during lectures when the fans were operating relative to lectures when the fans were not operating. This environmental effect explained about 30% of the variance in fatigue ratings and may be sufficient to affect adversely the attention of students within these settings.

Maintained attention and cognition during university lectures are complex, protracted processes whose proficiency and adaptability undergo state-dependent changes affected by context (Broadbent, Broadbent, & Jones, 1986; Smith, 1991). Although auditory stimuli whose characteristics compete with the domains of human speech are quickly disruptive during intense presentations (when sound level pressure exceeds 85 dB), the consequences of fluctuations in noise between 50 and 60 dB may also be significantly disruptive over time when they are continually present for longer durations. This experiment was designed to discern the effects of erratic, background fan noises during three 1-hr. lectures within a university classroom.

The capacity to discern information is primarily affected by the signal-to-noise ratio. For example, elementary-school children require a ratio of 20 dBA. If the average distance between the average speaker and the students is considered, background noise within the classroom should not exceed 30 dBA (Bradley, 1986). Despite the scientific evidence that background noise between 50 and 65 dB adversely affects attention and reduction in this amplitude encourages concentration (Hetu, Truchon-Gagnon, & Bilodeau,

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1990), the acoustic environment within many educational settings remains less than optimal.

There has been no systematic evaluation of the contribution to fatigue of erratic, complex sounds whose pressures erratically vary between 1 dB and 5 dB within the acceptable static background of 50 and 60 dB. Contemporary models of attention (Broadbent, *et al.*, 1986) predict that tasks which require constant filtering of auditory information such as that from lecture material should require greater inhibition of competing noise by functions typically associated with enhanced activity within the prefrontal cortices. A corollary of that hypothesis is that the greater subjective effort required to maintain this concentration (or to maintain the optimal subjective signal/noise ratio) should result in greater fatigue or tiredness over time (Persinger, 1980; Kjellberg, 1990).

The temporal component of fatigue from cumulative exposures to complex, erratic sounds is frequently ignored. For example, recent federal and provincial guidelines for renovation of classrooms require standards whose rationale are often derived from the subjective impressions of engineers exposed for short periods to low intensity but complex sounds. A pilot study by this experimenter indicated that those rooms in which recent "retrofits" had been completed (as defined by the installation of audible air-exchange systems) also showed the most frequent posted notices for canceled classes or the displacement of classes. These rooms had been considered "normal" by personnel who had installed the systems and who had remained while they were operating within the rooms for only a few minutes. During nonclass periods, very few students were observed to be studying within these rooms although adjacent more quiet rooms often contained several students.

METHOD

Subjects

A total of 21 second-year university students from a class of 35 students served as subjects. There were 10 men and 11 women whose ages ranged between 19 and 22 years. The only criterion for selection of the 21 students was their attendance at all of four successive lectures.

Procedure

At the end of each 50-min. lecture (10-min. intermission) of three 1-hr. periods (1900 hr. through 2200 hr. local time) each subject completed a brief questionnaire that requested the name, date, and time and an estimate of fatigue and concentration. For assessing the latter two subjective experiences, a summated rating scale was employed, using anchors of 1 through 7 for fatigue (1 = none, 4 = average, 7 = maximum) and for concentration (1 =

poor, 4 = normal, 7 = excellent). The subjects were told that the measurements were included in a study on the effects on fatigue and performance of 3-hr. and 1-hr. classes. There was never any reference to the ventilation system.

The experimental design involved an a-b-a-b presentation. During the first and third sessions an overhead ventilation (fan) system was operative while during the second and fourth sessions, the system, by arrangement, was not operative. These four successive sessions were selected because the lecture contents were similar and complex. The material involved diagnosis of patients from approximately 50 standardized neuropsychological, cognitive, and personality measurements.

During their operation, the background fans and duct system generated sound levels, as measured by a *Realistic* (Radio Shack) Sound level meter, that ranged continuously between 58 dB and 63 dB (weighting C) with occasional peaks at 70 dB, i.e., peak-to-peak difference greater than 10 dB around the (baseline) average. Within the regions below the fans (about one-quarter the area of the classroom), the sound levels ranged between 63 and 68 dB.

The output from the sound level meter to a Beckman electroencephalograph was extracted to assess the frequency of the amplitude modulation within the 5-dB fluctuations between 58 dB and 63 dB. The numbers of excursions (peaks) within the upper 33% of the 4 dB (peak to peak) variation per sec. were counted manually for the three successive 1-min. trains at a paper speed of 60 mm/sec. The mean and standard deviation for the three trains were 15.8 Hz and 5.4 Hz, respectively, and there was no significant difference (for t tests correlated data < 1.00) between the trains. The percentages of the record (time) occupied by the sound pressure fluctuations between 1 Hz and 30 Hz for successive 2 Hz increments are shown in Fig. 1. Although discriminability by paper speed and filters within the electroencephalograph could have accommodated up to 60 Hz (15 Hz, 35 Hz, and 50 Hz specific high-frequency filters), these ranges were not differentially detected within the criteria (cutoff) for amplitude fluctuations. Room temperature ranged between 21° and 24° C while relative humidity ranged between 30% and 40% during the four sessions. The four windows in the room were opened similarly each week.

The data for all three lectures per session were collected at the end of each session. Each subject's rating for fatigue and concentration for each of the three hours for each of the four days were loaded onto a VAX 4000 computer. Three-way analyses of variance with two levels repeated (fan off–fan on; first, second, or third hour) and one level not repeated (sex) were completed. To accommodate individual differences in subjective ratings, the relative fatigue and relative concentration were calculated for each subject by

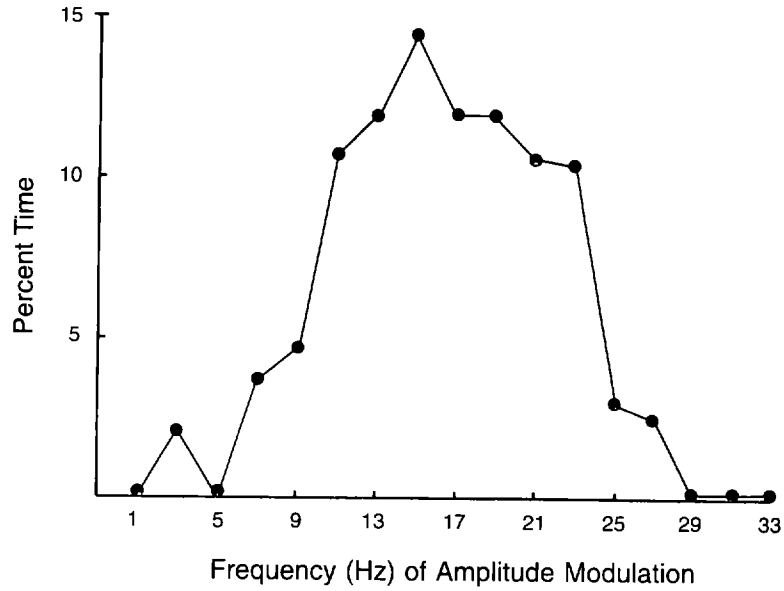

FIG. 1. Simulated "power spectra" of the frequency (sum of successive, 2-Hz increments) of the amplitude modulations between 1 and 5 dB superimposed upon a background field of 62 dB within the acoustic range from ventilation ducts and fans over a classroom

calculating a mean of all 12 measures (4 sessions × 3 hours) and then computing the quotient of each value divided by this mean. This and ancillary analyses such as the *post hoc t* tests for correlated data employed SPSS software.

RESULTS

The results of the repeated-measures analyses of variance indicated a statistically significant greater subjective fatigue ($F_{1,20}=8.65$, $p<.01$, $\eta^2=30\%$) for those lecture periods when the fans were operative relative to when they were not operative. The mean and standard deviation for subjective fatigue ratings when the fans were off were 3.6 and 0.7; these values for the lectures when the fans were on were 4.1 and 0.9, respectively. The enhanced reported fatigue was also significantly higher when the fans were operative ($F_{1,20}=9.59$, $p<.01$; $\eta^2=32\%$) when the hourly estimates of fatigue were referenced to each individual's mean rating for the entire experiment. There was no statistically significant effect of fan operation upon the subjective evaluations of concentration ($F_{1,20}<2.50$, $p>.05$) for either the direct or relative estimates. There were no statistically significant interactions between the factorial combinations of the conditions, fans on or off, hour of the rating, and sex for either the subjective ratings of fatigue or of concentration.

Discussion

These results indicated that even "low level" but complex background sound from ventilation systems within university classrooms may affect students' estimates of subjective fatigue. The effect size (accommodating 30% of the variance in estimates of fatigue) would be sufficient to affect performance when it was required over a prolonged period (such as 3 × 50-min. lectures) but might not be detectable during the brief sampling periods (such as 5 min.) that are often employed by design engineers and maintenance personnel to estimate the interference by sounds produced by ventilation or heating equipment.

Three-hour classes, especially during the evening hours, have become a frequent component of continuing education programs. Because many of these adults also maintain daytime employment, they could be particularly vulnerable to the negative effects of continuous, complex, background sounds within the classroom. The effect of fatigue would also adversely affect the quality and palatability of the learning experience. Previous work (Kjellberg, 1990) concerning the influence of sound pressure upon performance has emphasized "steady-state" background sound pressure levels. The present results indicate that the serial or frequency variations of continuous amplitude modulations superimposed upon complex carrier frequencies within the audible range may adversely affect subjective experiences even at traditionally acceptable static pressures of about 60 to 65 dB.

The processes by which erratic fluctuations of sound pressure (even with low magnitudes between 1 dB and 5 dB within a background of about 60 dB) affect subjective fatigue remains to be examined. One possible explanation could involve "auditory driving" of neuroelectrical activity. The temporal characteristics of the peak-to-peak changes in the amplitude from the ventilation fans were within the range of electroencephalographic activity. As indicated by the mean and the standard deviation of the amplitude modulations per second, the class was exposed to variations of sound pressure between 10 and 20 Hz for 68% of the time and to variations between 5 and 25 Hz 95% of the time. The primary power spectra for the electroencephalogram occupies this range (Barlow, 1993). The time course of the high-frequency coherence between various regions of the cerebral cortices, a powerful correlate of "awareness," concentration, and perceptual filtering, is between 50 msec. and 200 msec. or between 5 and 20 Hz (Silberstein, 1995).

Protracted, distractive volleys of low-level subcortical input to the temporal cortices (Nunez, 1995) would be expected to affect the understanding and interpretation of language (Kolb & Whishaw, 1990) over time when the amount and rate of information are above average and primarily auditory (such as a university lecture). To maintain concentration and attention the required inhibition of "neuronal noise" would result in an increasing load

upon the prefrontal cortices. The cumulative effects of the maintained inhibition might be experienced as or accompanied by fatigue.

There might also be nonspecific effects of this fatigue upon the learning process. Considering the likely role of the mesiobasal (amygdala) portions of the temporal lobes that strongly affect hedonistic properties (unpleasant/pleasant) of experiences (Davis, 1994), the persistent interruption of attention could influence the 'perceptual palatability" of the lecture room. As a result, lectures within these settings would encourage aversion to the setting. The aversion might be manifested by reduced class attendance over time and by attribution of this "negative affect" to both the lecturer and the course material.

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